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# EVALUATION OF THE EFFECT OF PROCESSING PARAMETERS ON THE ADHESIVE BONDING OF GLASS-REINFORCED PLASTICS

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Shear strength data for bonds made by adhesively bonding a glass-reinforced plastic (XP-114 epoxy laminate) with three different adhesives (Epon 828/V-140, EC-2214, AF-126) are examined statistically. It is shown that surface exposure time (SET) up to 30 days appears to be immaterial for AF-126 bonds but that shorter SET times give somewhat better bonds in the other cases. Machine sanding leads to better results than hand sanding | | |

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20. ABSTRACT (Continued)

for the EC-2214 and AF-126 systems. No appreciable difference between hand or machine sanding was discerned for the Epon 828/V-140 system. Only in the case of AF-126 were bond strengths significantly lower after aging 30 days at 120°F (49°C) and 95% RH. These results indicate that the effect of processing parameters on resultant bond strengths is highly dependent on the adhesive system used in bonding the glass-reinforced plastic.

Methods are described and curves are shown illustrating how smoothed distribution curves of bond strength can be used to observe data overlap and differences. Such methods can be helpful to the engineer in deciding on tradeoffs involving sacrificing a little in optimum properties in order to attain maximum fabrication ease and efficiency.

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## INTRODUCTION

In an earlier report (ref. 1), the effects of several processing variables on the strength and durability of adhesive-bonded, glass-reinforced plastic were investigated. Three adhesives (Epon 828/V-140, EC-2214, AF-126) were used with a four-ply, bioriented, glass-reinforced epoxy laminate (3M XP-114). Variables studied included surface exposure time (SET) from 1-4 hours up to 30 days, hand sanding as compared to machine sanding in surface preparation, and conditioning for 7 days at 73°F (23°C) and 50% RH and for 30 days at 120°F (49°C) and 95% RH.

The work reported in reference 1 involved the generation of a significant volume of shear strength data after each of the various treatments. However, interpretation of the results was not always entirely straightforward because the differences in strength after the various treatments, while frequently appreciable, tended to be relatively small with a good deal of data overlap. The use of average strength values often raised a question as to whether the differences were really significant. In this report, we re-examine the data using simple statistical approaches. Thus, it is possible to determine the cases where the differences were statistically significant. These determinations make it easier to specify the occasions where explanations of differences are really required.

The shear strength data for the three adhesives bonded to the glass reinforced plastic are graphically summarized in figure 1. The distribution curve for each set of data was determined by using the two parameters calculated for the linear Weibull distribution function. Each distribution curve in the figure represents a statistically significant entity, as determined by the significance tests discussed later in this report. For example, comparing the curves for adhesive AF-126, shows that machine sanding leads to somewhat stronger bonds than hand sanding. Also, the 7 days aging of AF-126 results in stronger shear strengths than the harsh environment conditions. Details of the similarities and differences are also discussed later in this report. Figure 1 is used only to illustrate the overlap in data and the statistically significant differences; the curves are calculated from the linearized Weibull parameters and hence represent the primary data as smoothed curves. An estimate of the quality of fit is given by the correlation coefficients in table 1 for the linear Weibull plots.

The basic detailed data in reference 1 was recorded as breaking loads (pounds or newtons) and these units are used in the current report. The shear strength specimens were 2.54 cm (1 inch) wide with a 1.27 cm (0.5 inch) overlap.

## RESULTS AND DISCUSSION

Note. The experimental procedures are given in detail in reference 1.

### Epon 828/V-140

The raw data for this adhesive system is in table 2. For convenience, the values are arranged in the order of increasing breaking load; and, the surface exposure time (SET) is coded beside each value.

Examination of table 2 indicates that, although there is a conderable overlapping of data, the values after 30 days SET appear to be somewhat low. To test this observation, the Wilcoxon Sum of Ranks test was used (refs. 2-4). In order to illustrate this method, the data from column 1 of table 2 is reproduced in table 3 which shows that the test determines if the 30 hours SET data (code VI) is significantly lower than the other values. Note that the data is in two groups (A and B). Rank values are obtained by numbering and it should also be noted that numbering may be either from bottom to top or from top to bottom because a significant difference may exist on either the low or the high side. In the present case, the B values are near the top and the numbering from top to bottom is sufficient. In any case, the sum of the A rank or B rank column that gives the smallest number is the one used in the test. In table 3 this sum is R = 19.5 as shown.

In determining if the A and B ranks are significantly different, table 4 can be used with up to 20 measurements in each sample. With more than 20 measurements in one or both samples, the significance of the smaller rank total (R) is found by calculating Z from the formula

$$Z = \frac{n_R(n_A+n_B+1) - 2R}{\left(\dfrac{n_A n_B(n_A+n_B+1)}{3}\right)^{\frac{1}{2}}} \tag{1}$$

Where $n_R$ is the number of measurements in whichever sample gives the smaller rank total. It may equal either $n_A$ or $n_B$ depending on the circumstances. Values of Z corresponding to important probability levels are as follows:

Z Table

| | | | |
|---|---|---|---|
| P = 10% | P = 5% | P = 1% | P = 0.2% |
| Z = 1.64 | Z = 1.96 | Z = 2.58 | Z = 3.09 |

Since in table 3 the A samples consist of 25 measurements ($n_A$ = 25) and there are 5 values in the B samples ($n_B$ = 5), we must use equation 1 and the above Z table. From table 3, Z = 3.22 in equation 1. From the Z table above P is less than 0.2%. This means that in less than one case in 500 these results would have been obtained by chance. Usually anything less than one chance in 20 (i.e., P = 5%) is taken to mean that there is a significant difference. In this case, the 30 days SET strengths are interpreted as being significantly lower than the remaining data.

The Wilcoxon Sum of Ranks test was applied to each of the other 3 columns of table 2 in testing for differences between 30 days SET and the other SET values combined. The following results were obtained:

| | | | |
|---|---|---|---|
| 7 days aging - Hand sanding<br>Compare: To 14 days with 30 days SET | Z = 3.22 | $P<0.2\%$ | Significant difference |
| 7 days aging - Machine sanding<br>Compare: To 14 days with 30 days SET | Z = 3.22 | $P>5\%$ | Probably no significant difference |
| 30 days aging - Hand sanding<br>Compare: To 14 days with 30 days SET | Z = 2.14 | $P<5\%$ | Probably a significant difference |
| 30 days aging - Machine sanding<br>Compare: To 14 days with 30 days SET | Z = 2.67 | $P<1\%$ | Significant difference |

Thus, in 3 out of 4 cases the 30 days SET test results appear to be significantly low. For the 7 days, 73°F (23°C), 50% RH with machine sanding, P is slightly more than 5%, so that 30 days SET does not appear to be significantly low in this case. By tentatively assuming that the data in table 2 may be combined, and using the Wilcoxon

rank test to compare all 30 days SET with all SET up to 14 days, the following results were obtained:

All data

| | | | | |
|---|---|---|---|---|
| Compare: | To 14 days with 30 days SET | $Z = 4.64$ | $P<0.2\%$ | Very significant difference |

The foregoing results clearly indicate that using 30 days SET will probably degrade the bond strength to some extent. Therefore, this condition (30 days SET) was eliminated for the Epon 828/V-140 system and is not included in the subsequent discussion.

The next questions that were addressed for the SET data up to 14 days involved any differences between hand and machine sanding as well as possible difference between 7 days, 73°F (23°C), 50% RH and 30 days, 120°F (49°C), 95% RH. Eliminating 30 days SET data and tentatively assuming that all the remaining data in table 2 does not differ significantly, the Wilcoxon Sum of Ranks test was used to test for possible differences arising from hand or machine sanding and between the two conditioning treatments. For the comparison of the conditioning treatments the results are:

To 14 days SET - Hand sanding

| | | | | |
|---|---|---|---|---|
| Compare: | 7 days with 30 days aging | $Z = 1.06$ | $P>10\%$ | No significant difference |

To 14 days SET - Machine sanding

| | | | | |
|---|---|---|---|---|
| Compare: | 7 days with 30 days aging | $Z = 0.38$ | $P>10\%$ | No significant difference |

And for the comparison of hand and machine sanding:

To 14 days SET - 7 days and 30 days aging

| | | | | |
|---|---|---|---|---|
| Compare: | Hand with machine sanding | $Z = 1.46$ | $P>10\%$ | No significant difference |

With the elimination of 30 days SET, it appears that there are no discernible differences in bond strengths after either hand or machine sanding, or after either of the aging conditions.

The above discussion is based on the tentative assumption that there are no significant differences in SET times from 1-4 hours to 14 days. This assumption proved to be not completely true upon testing. The 1-4 hours SET appears to show a small but probably

significant difference on the high side. The comparison, using the same procedure as before, gave the following results:

| | | | | |
|---|---|---|---|---|
| All data | | | | |
| Compare: | 1-4 hr SET with 1-14 days SET | Z = 2.75 | P<1% | Probably significant difference |

Since the data (based on the above) must be divided into two groups, namely 1-4 hours SET and 1-14 days SET, the equivalence of hand and machine sanding and of the 7 days and 30 days aging were checked for each group. For the 1-4 hour SET the results are:

| | | | | |
|---|---|---|---|---|
| Compare: | Hand with machine | Table 5 | P>5% | No significant difference |
| 1-4 hr SET | | | | |
| Compare: | 7 days with 30 days aging | Table 5 | P>10% | No significant difference |

For the 1-14 days SET the test gave the following:

| | | | | |
|---|---|---|---|---|
| 1-14 days SET | | | | |
| Compare: | Hand with machine sanding | Z = 0.66 | P>10% | No significant difference |
| 1-14 days SET | | | | |
| Compare: | 7 days with 30 days aging | Z = 0.57 | P>10% | No significant difference |

For bonding glass-reinforced plastic with Epon 828/V-140, one may conclude that hand and machine sanding are equivalent. Aging for 30 days at 120°F (49°C) and 95% RH has no appreciable effect on shear strength. There is a small decrease in strength for SET times of 1-14 days are compared to SET = 1-4 hours, although there is a considerable overlap in the data. Figures 1 and 2 show the general magnitude of this loss of strength at the longer SET times.

For each set of data, i.e., SET = 1-4 hours and SET = 1-14 days, the Weibull distribution was found to describe the data reasonably well. The Weibull distribution function was used in the form (refs. 5,6):

$$\log\log\left[\frac{1}{1-F(X)}\right] = -\log\alpha + \beta\,(X-\gamma) \tag{2}$$

Where F(X) is the distribution function, i.e., the fraction of samples failing at a breaking load (lbs or N) of X or less, X corresponds to the breaking load values and $\alpha$, $\beta$, and $\gamma$ are the parameters of the distribution. A plot of the left-hand side of equation 2 versus log $(X-\gamma)$ should give a straight line. $\gamma$ may be selected on an iterative basis by making trial plots: $\alpha$ and $\beta$ are evaluated from the slope and intercept.

In application to the data, all data points (20 or more) are tabulated in order of increasing breaking load. F(X) is calculated on a point-by-point basis (i.e., the fraction failing at X or below) and log log $\left[\frac{1}{1-F(X)}\right]$ is plotted against log X. A computer was used to calculate linear correlation coefficients. For our purposes, taking $\gamma = 0$ (using a two-parameter Weibull distribution) appears to be satisfactory.

The linear Weibull plots for the Epon 828/V-140 adhesive system are shown in figure 3. The correlation coefficient is 0.956 for 1-4 hours SET and 0.977 for 1-14 days SET (table 1). These plots reinforce the previous finding that the 1-4 hour SET gives bonds that are a little stronger, although there is much overlap of data.

Although figure 3 may be used to indicate the overlap and difference in breaking strength for 1-4 hour and 1-14 days SET, it is probably easier to make these comparisons using the appropriate differential distribution plots (fig. 1). The curves in figure 1 were calculated by (ref. 6):

$$f(X) = \frac{b}{a}\left[\frac{X}{a}\right]^{b-1} e^{-\left(\frac{X}{a}\right)^{b}} \qquad (3)$$

In equation 2, $\alpha = b \log a - 0.36$ and $\beta = b$, so that:

$$\log \log \left[\frac{1}{1-F(X)}\right] = - b \log a - 0.36 + b \log X \qquad (4)$$

Having determined $\alpha$ and $\beta$ in equation 2 from the intercept and slope of the straight line (fig. 3), we can now estimate a and b in equations 3 and 4. For example, for the 1-4 hour SET in figure 3, the equation of the straight line is:

$$\log \log \left[\frac{1}{1-F(X)}\right] = - 35.4 + 12.0 \log X$$

$$\beta = b = 12.0$$

$$\alpha = - b \log a - 0.36 = 12.0 \log a - 0.36 = - 35.4$$

$$\log a = \frac{35.04}{12.0}$$

$$a = 830$$

These values of a and b are then used in equation 3. For selected values of X over the range of interest, the frequency ($f(X)$) is then calculated by equation 3 and plotted as in figure 1. Figure 2 shows both the overlap of data and the differences between 1-4 hour SET and 1-14 days SET for the Epon 828/V-140 system. The user of the adhesive will have to decide if the small degradation in strength which occurs from using a convenient SET time of more than a few hours is acceptable.

EC-2214

The raw data for this adhesive system are shown in table 5. For convenience, the values have been arranged in order of increasing breaking load and the surface exposure time (SET) has been coded beside each value.

The general method used to examine Epon 828/V-140 data was also used to examine the EC-2214 adhesive. For the EC-2214, the 30 days SET loads were very noticeably low. A summary of the Wilcoxon Sum of Ranks test applied to each column of table 5 is given below. These tests compare 30 days SET with all SET times through 14 days.

| | | | |
|---|---|---|---|
| 7 days aging - Hand sanding | | | Significant |
| Compare: To 14 days with 30 days SET | $Z = 2.92$ | $P<1\%$ | difference |
| 30 days aging - Hand sanding | | | Significant |
| Compare: To 14 days with 30 days SET | $Z = 2.61$ | $P<0.2\%$ | difference |
| 30 days aging - Hand sanding | | | Significant |
| Compare: To 14 days with 30 days SET | $Z = 3.08$ | $P\cong 0.2\%$ | difference |
| 30 days aging - Machine sanding | | | Significant |
| Compare: To 14 days with 30 days SET | $Z = 3.31$ | $P<0.2\%$ | difference |

Since, in every case, the 30 days SET breaking loads were significantly lower than the others, the 30 days values were eliminated from further consideration.

For each aging condition, difference between hand and machine sanding were studied for all SET times through 14 days. The results are given below:

| | | | |
|---|---|---|---|
| To 14 days SET - 7 days aging | | | Significant |
| Compare: Hand with machine sanding | $Z = 2.63$ | $P \cong 1\%$ | difference |

| | | | |
|---|---|---|---|
| To 14 days SET - 30 days aging | | | Significant |
| Compare: Hand with machine sanding | $Z = 4.57$ | $P < 0.2\%$ | difference |

In contrast to the Epon 828/V-140 case, the EC-2214 bonded composites gave significantly weaker bonds after hand sanding. On the other hand, the 30 days at 120°F (49°C) and 95% RH gave strengths equivalent to those after 7 days at 73°F (23°C) and 50% RH as shown below:

| | | | |
|---|---|---|---|
| To 14 days SET - Hand sanding | | | No significant |
| Compare: 7 days with 30 days aging | $Z = 0.94$ | $P > 10\%$ | difference |

| | | | |
|---|---|---|---|
| To 14 days SET - Machine sanding | | | No significant |
| Compare: 7 days with 30 days aging | $Z = 0.37$ | $P > 10\%$ | difference |

As in the previous system, the above tests were based on the tentative assumption that there are no significant differences in SET times between 1-4 hours and 14 days. Once more, this assumption proved to be not completely true. The 1-4 hours SET appears to show a relatively small but probably significant higher breaking strength. The comparison by Wilcoxon's Sum of Ranks of 1-4 hour SET with the other values up to 14 days produced the following results:

| | | | |
|---|---|---|---|
| Machine sanding - 7 days aging - | | | |
| 30 days aging | | | Significant |
| Compare: To 14 days with 1-4 hr SET | $Z = 3.02$ | $P < 1\%$ | difference |

| | | | |
|---|---|---|---|
| Machine Sanding - 7 days aging - | | | Probably |
| 30 days aging | | | significant |
| Compare: To 14 days with 1-4 hr SET | $Z = 2.46$ | $P < 5\%$ | difference |

Since the data based on the above must be divided into 2 groups, mainly 1-4 hours SET and 1-14 days SET, the difference between hand and machine sanding and the equivalence of 7 and 30 days aging found above were checked for each group. The conclusions drawn above remained unchanged after these tests.

For each of the four sets of data identified above (hand sanding, 1-4 hours SET; hand sanding, 1-14 days SET; machine sanding, 1-4 hours SET; machine sanding, 1-14 days SET), the two-parameter linear Weibull line was plotted according to equation 2. The plots are shown in figure 4. The least square lines are drawn and the correlation coefficients are given in table 6. It should be noted that for the 1-4 hours SET data, since there were less than 20 points, a table of plotting positions was used to make an adjustment for the smallness of the sample size (refs. 5,6).

The differential distribution curves for the EC-2214 data shown in figure 5 were calculated by equation 3 using the parameters from the linear Weibull plots and the procedure described in the prior discussion of Epon 828/V-140. For this system, it is evident that machine sanding in surface preparation leads to somewhat improved bonds when compared to hand sanding. Aging for 30 days at 120°F (49°C) and 95% RH has no appreciable effect on bond strength. 1-4 hours SET gives somewhat better bonds than the longer SET times. The data overlap and general magnitude of this effect are shown in figure 5.

## AF-126

The raw data for the AF-126 system is in table 6. As in tables 2 and 5, the values are in the order of increasing breaking load and the surface exposure time (SET) is coded.

Use of the Wilcoxon Sum of Ranks test indicated that SET was immaterial for this system, i.e., that essentially the same breaking loads were observed at SET from a few hours up to 30 days. However, the test comparing hand and machine sanding indicated that the differences are probably significant, as indicated below:

| | | | |
|---|---|---|---|
| All SET - 7 days aging<br>Compare: Hand with machine sanding | $Z = 2.28$ | $P<5\%$ | Probably significant difference |
| All SET - 30 days aging<br>Compare: Hand with machine sanding | $Z = 3.24$ | $P<0.2\%$ | Significant difference |

Despite a good deal of data overlap, it appears that the machine sanding produced stronger bonds.

A comparison of the 7 days and 30 days aging also indicated that 30 days at 120°F (49°C) and 95% RH degraded the bonds significantly. The test results are given below:

| | | | | |
|---|---|---|---|---|
| A11 SET - Machine sanding | | | | Significant |
| Compare: | 7 days with 30 days aging | $Z = 2.81$ | $P<1\%$ | difference |
| S11 SET - Hand sanding | | | | Significant |
| Compare: | 7 days with 30 days aging | $Z = 3.21$ | $P<0.2\%$ | difference |

The significant differences described above using the simple rank tests were verified by a more effective t-test which was performed because the data indicated a large overlap. (The rank tests tend to give slightly higher probability levels than their more complicated alternatives (ref. 2)).

The t-test for testing two independent random samples generally fits experiments for comparing the effects of two treatments (ref. 7). This is the situation that obtains in the present case. The necessary data for accomplishing this test are shown in summary table 7. In this table "hand" and "machine" refer to the type of sanding, 7 days represents 7 days at 73°F (23°C) and 50% RH and 30 days corresponds to 30 days at 120°F (49°C) and 95% RH. n is the number of data points, DF = n-1 is degrees of freedom, $\overline{Y}$ is the mean, and $Y_1$ represents the value of an individual data point. The sum of squares is obtained by determining individual differences between the data value and the mean, squaring, and then summing the squares.

The t-test may now be illustrated with a sample calculation. For this purpose we will compare hand and machine sanding where the samples were tested after 7 days at 73°F (23°C) and 50% RH. The pooled estimate of variance is

$$s^2 = \frac{\Sigma(Y_1-\overline{Y}_1)^2 + \Sigma(Y_2-\overline{Y}_2)^2}{n_1 + n_2 - 2}$$

And from table 7

$$s^2 = \frac{457,400 + 375,800}{58} = 14,400$$

The variance of the difference between the means is:

$$s_d^{\,2} = s^2 \left(\frac{1}{n} + \frac{1}{n}\right) = 14{,}400 \left(\frac{2}{30}\right)$$

$$s_d^{\,2} = 960$$

and the standard deviation of d is:

$$s_d = \sqrt{960} = 31$$

and;

$$t = \frac{\overline{Y}_1 - \overline{Y}_2}{s_d} = \frac{1150 - 1080}{31} = 2.26$$

In order to test for significant differences, we use the t-test table (table 8). Entering this table at DF = 58, we can interpolate between 40 and 60. Actually the difference is so small we can approximate with DF = 60. We immediately see that for t = 2.26, P is below 5% and the difference is probably statistically significant.

Using this procedure, the results shown below were obtained for the AF-126 system:

| Comparison | | | |
|---|---|---|---|
| Hand sanding - 7 days aging with Machine sanding - 7 days aging | t = 2.26 | P<5% | Probably significant difference |
| Hand sanding - 30 days aging with Machine sanding - 30 days aging | t = 4.07 | P<0.2% | Very significant difference |
| Hand sanding - 7 days aging with Hand sanding - 30 days aging | t = 3.87 | P<0.2% | Very significant difference |
| Machine sanding - 7 days aging with Machine sanding - 30 days aging | t = 2.96 | P<1% | Significant difference |

These results agree in all cases with our findings using the Wilcoxon Sum of Ranks test and lend added confidence to the validity of our conclusions.

Linear Weibull distribution plots were made for this system following the procedures described earlier in this report. These lines are shown in figure 6 and the corresponding correlation coefficients are recorded in table 1.

The appropriate differential distribution curves for the AF-126 data are shown in figure 7. The curves were calculated by equation 3 using the parameters from the linear Weibull plots and the procedure that was described in the discussion of Epon 828/V-140. For this system it is evident that preparing the surface by machine sanding produces stronger bonds than hand sanding. Aging for 30 days at 120°F (49°C) and 95% RH results in some degradation of the bond. SET up to 30 days is immaterial for this system. The data overlap and the magnitude of the differences are shown in figure 7.

## Comparison of Adhesives

Examination of figure 1 indicates that the AF-126 adhesive forms the strongest bonds, followed by EC-2214, with Epon 828/V-140 showing the lowest breaking loads. This breaking load order is illustrated in simplified form in figure 8 in which the curves for the optimum conditions of each adhesive are shown. For AF-126 the optimum conditions are machine sanding, 7 days aging, and SET immaterial. For EC-2214 the conditions are machine sanding, 1-4 hours SET, and aging condition immaterial. For Epon 828/V-140 optimum conditions correspond to 1-4 hours SET with the type of sanding and the aging time making no difference.

# CONCLUSIONS

1. The effect of the processing parameters on the shear strength in bonding glass-reinforced plastics is highly dependent on the adhesive system used.

2. Statistical methods are useful in evaluating the shear strength results.

3. Smoothed distribution curves, representing the bond strength data, can be helpful in deciding on trade-offs involving sacrificing a little in the optimum bonding properties in order to attain maximum fabrication ease and efficiency. The curves can also be useful in comparing adhesives.

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Table 1. Correlation coefficients for the linear Weibull distribution plots

| | Correlation coefficient | |
|---|---|---|
| | 1-4 hours SET | 1-14 days SET |
| Epon 828/V-140 | 0.956 | 0.977 |

| | Correlation coefficient | | | |
|---|---|---|---|---|
| | Hand sanding 1-4 hrs SET | Hand sanding 144 days SET | Machine sanding 1-4 hrs SET | Machine sanding 1-14 days SET |
| EC-2214 | 0.835 | 0.973 | 0.994 | 0.990 |

| | Correlation coefficient | | | |
|---|---|---|---|---|
| | Hand - 7 days | Hand - 30 days | Machine - 7 days | Machine - 30 days |
| AF-126 | 0.980 | 0.976 | 0.988 | 0.979 |

Table 2. Breaking loads for the system glass-reinforced plastic bonded with Epon 828/V-140

| Hand sanding<br>7 days at 73°F + 50% RH | | Machine sanding<br>7 days at 73°F + 50% RH | | Hand sanding<br>30 days at 120°F + 95% RH | | Machine sanding<br>30 days at 120°F + 95% RH | |
|---|---|---|---|---|---|---|---|
| N | LBS | N | LBS | N | LBS | N | LBS |
| 2370 | 532 (VI) | 2560 | 575 (VI) | 2650 | 595 (VI) | 2890 | 650 (VI) |
| 2630 | 590 (VI) | 2740 | 615 (V) | 2890 | 650 (II) | 2980 | 670 (VI) |
| 2710 | 608 (VI) | 2760 | 620 (II) | 2910 | 655 (VI) | 3030 | 680 (VI) |
| 2830 | 635 (I) | 2780 | 625 (VI) | 3000 | 675 (IV) | 3050 | 685 (II) |
| 2890 | 650 (V) | 2830 | 635 (II) | 3000 | 675 (V) | 3120 | 700 (IV) |
| 3000 | 674 (VI) | 2850 | 640 (V) | 3070 | 690 (IV) | 3140 | 705 (III) |
| 3090 | 695 (VI) | 2870 | 645 (IV) | 3120 | 700 (IV) | 3160 | 710 (VI) |
| 3090 | 695 (II) | 2910 | 655 (V) | 3120 | 700 (VI) | 3200 | 720 (II) |
| 3120 | 700 (V) | 2980 | 670 (IV) | 3140 | 705 (V) | 3200 | 720 (IV) |
| 3140 | 705 (II) | 3140 | 705 (II) | 3140 | 705 (V) | 3230 | 725 (II) |
| 3230 | 725 (IV) | 3180 | 715 (VI) | 3200 | 720 (VI) | 3250 | 730 (II) |
| 3230 | 725 (V) | 3320 | 745 (III) | 3200 | 720 (III) | 3340 | 750 (II) |
| 3290 | 740 (III) | 3400 | 765 (VI) | 3230 | 725 (I) | 3350 | 752 (V) |
| 3320 | 745 (V) | 3450 | 775 (III) | 3230 | 725 (III) | 3360 | 755 (I) |
| 3360 | 755 (IV) | 3470 | 780 (V) | 3230 | 725 (IV) | 3380 | 760 (III) |
| 3380 | 760 (I) | 3520 | 790 (I) | 3270 | 735 (VI) | 3400 | 765 (IV) |
| 3380 | 760 (II) | 3540 | 795 (VI) | 3290 | 740 (V) | 3400 | 765 (VI) |
| 3380 | 760 (III) | 3560 | 800 (III) | 3290 | 740 (V) | 3470 | 780 (I) |
| 3470 | 780 (V) | 3560 | 800 (IV) | 3360 | 755 (II) | 3470 | 780 (III) |
| 3490 | 785 (I) | 3650 | 820 (II) | 3360 | 755 (II) | 3490 | 785 (IV) |
| 3490 | 785 (IV) | 3720 | 835 (V) | 3400 | 765 (II) | 3580 | 804 (V) |
| 3560 | 800 (I) | 3740 | 840 (III) | 3430 | 770 (I) | 3590 | 806 (V) |
| 3560 | 800 (I) | 3760 | 845 (I) | 3470 | 780 (IV) | 3600 | 810 (I) |
| 3560 | 800 (IV) | 3830 | 860 (III) | 3520 | 790 (III) | 3680 | 826 (V) |
| 3580 | 805 (II) | 3940 | 885 (I) | 3540 | 795 (I) | 3690 | 830 (IV) |
| 3670 | 825 (III) | 4010 | 900 (II) | 3600 | 810 (I) | 3740 | 840 (I) |
| 3760 | 845 (III) | 4010 | 900 (IV) | 3630 | 815 (II) | 3780 | 850 (V) |
| 3800 | 855 (IV) | 4210 | 945 (I) | 3720 | 835 (II) | 3800 | 855 (I) |
| 3890 | 875 (II) | 4210 | 945 (IV) | 3890 | 875 (III) | 3890 | 875 (III) |
| 3960 | 890 (III) | 4450 | 1000 (I) | 4050 | 910 (I) | 3920 | 880 (III) |

I = 1-4 hrs SET; II = 1 day SET; III = 2 days SET;

IV = 7 days SET; V = 14 days SET; VI = 30 days SET

Table 3. Use of Wilcoxon Sum of Ranks test to determine if 30 days SET values differ significantly from the remaining data. Epon 828/V-140, hand sanding, 7 days at 73°F and 50% RH

| Data value PSI | N | | Tally | | Rank value | B Ranks |
|---|---|---|---|---|---|---|
| 2320 | 532 | B | | B | 1 | 1 |
| 2630 | 590 | B | | B | 2 | 2 |
| 2710 | 608 | B | | B | 3 | 3 |
| 2830 | 635 | A | A | | 4 | |
| 2890 | 650 | A | A | | 5 | |
| 3000 | 674 | B | | B | 6 | 6 |
| 3090 | 695 | AB | A | B | 7,8 | 7,5 |
| 3120 | 700 | A | A | | 9 | |
| 3140 | 705 | A | A | | 10 | |
| 3230 | 725 | AA | AA | | 11,12 | |
| 3290 | 740 | A | A | | 13 | |
| 3320 | 745 | A | A | | 14 | |
| 3360 | 755 | A | A | | 15 | |
| 3380 | 760 | AAA | AAA | | 16,17,18 | |
| 3470 | 780 | A | A | | 19 | |
| 3490 | 785 | AA | AA | | 20,21 | |
| 3560 | 800 | AAA | AAA | | 22,23,24 | |
| 3580 | 805 | A | A | | 25 | |
| 3670 | 825 | A | A | | 26 | |
| 3760 | 845 | A | A | | 27 | |
| 3800 | 855 | A | A | | 28 | |
| 3890 | 875 | A | A | | 29 | |
| 3960 | 890 | A | A | | 30 | |
| | | | | | | R = 19.5 |

B = 30 days SET A = All other SET values

$$Z = \frac{5(25+5+1) - 2\ (19.5)}{\left(\frac{(5)(25)(25+5+1)}{3}\right)^{\frac{1}{2}}} = 3.22$$

Table 4. R tables for the Wilcoxon Sum of Ranks test

| $n_A$ | $n_B$ | P = 10% | P = 5% | P = 1% | P = 0·2% |
|---|---|---|---|---|---|
| 2 | 8 | 4 | 3 | — | — |
| 2 | 9 | 4 | 3 | — | — |
| 2 | 10 | 4 | 3 | — | — |
| 2 | 11 | 4 | 3 | — | — |
| 2 | 12 | 3 | 4 | — | — |
| 2 | 13 | 3 | 4 | — | — |
| 2 | 14 | 6 | 4 | — | — |
| 2 | 13 | 6 | 4 | — | — |
| 2 | 16 | 6 | 4 | — | — |
| 2 | 17 | 6 | 5 | — | — |
| 2 | 18 | 7 | 5 | — | — |
| 2 | 19 | 7 | 5 | 3 | — |
| 2 | 20 | 7 | 5 | 3 | — |
| 3 | 5 | 7 | 6 | — | — |
| 3 | 6 | 8 | 7 | — | — |
| 3 | 7 | 8 | 7 | — | — |
| 3 | 8 | 9 | 8 | — | — |
| 3 | 9 | 10 | 8 | 6 | — |
| 3 | 10 | 10 | 9 | 6 | — |
| 3 | 11 | 11 | 9 | 6 | — |
| 3 | 12 | 11 | 10 | 7 | — |
| 3 | 13 | 12 | 10 | 7 | — |
| 3 | 14 | 13 | 11 | 7 | — |
| 3 | 13 | 13 | 11 | 8 | — |
| 3 | 16 | 14 | 12 | 8 | — |
| 3 | 17 | 15 | 12 | 8 | 6 |
| 3 | 18 | 13 | 13 | 8 | 6 |
| 3 | 19 | 16 | 13 | 9 | 6 |
| 3 | 20 | 17 | 14 | 9 | 6 |
| 4 | 4 | 11 | 10 | — | — |
| 4 | 3 | 12 | 11 | — | — |
| 4 | 6 | 13 | 12 | 10 | — |
| 4 | 7 | 14 | 13 | 10 | — |
| 4 | 8 | 15 | 14 | 11 | — |
| 4 | 9 | 16 | 14 | 11 | — |
| 4 | 10 | 17 | 13 | 12 | 10 |
| 4 | 11 | 18 | 16 | 12 | 10 |
| 4 | 12 | 19 | 17 | 13 | 10 |
| 4 | 15 | 20 | 18 | 15 | 11 |
| 4 | 14 | 21 | 19 | 14 | 11 |
| 4 | 15 | 22 | 20 | 13 | 11 |
| 4 | 16 | 24 | 21 | 13 | 12 |
| 4 | 17 | 23 | 21 | 16 | 12 |
| 4 | 18 | 26 | 22 | 16 | 13 |
| 4 | 19 | 27 | 23 | 17 | 13 |
| 4 | 20 | 28 | 24 | 18 | 13 |
| 5 | 5 | 19 | 17 | 15 | — |
| 5 | 6 | 20 | 18 | 16 | — |
| 5 | 7 | 21 | 20 | 16 | — |
| 3 | 8 | 23 | 21 | 17 | 15 |
| 3 | 9 | 24 | 22 | 18 | 16 |
| 5 | 10 | 26 | 23 | 19 | 16 |
| 3 | 11 | 27 | 24 | 20 | 17 |
| 3 | 12 | 28 | 26 | 21 | 17 |
| 5 | 13 | 30 | 27 | 22 | 18 |
| 3 | 14 | 31 | 28 | 22 | 18 |
| 3 | 15 | 33 | 29 | 23 | 19 |
| 3 | 16 | 34 | 30 | 24 | 20 |
| 3 | 17 | 33 | 32 | 23 | 20 |
| 5 | 18 | 37 | 33 | 26 | 21 |
| 5 | 19 | 38 | 34 | 27 | 22 |
| 5 | 20 | 40 | 33 | 28 | 22 |
| 6 | 6 | 28 | 26 | 23 | — |
| 6 | 7 | 29 | 27 | 24 | 21 |
| 6 | 8 | 31 | 29 | 25 | 22 |
| 6 | 9 | 33 | 31 | 26 | 23 |
| 6 | 10 | 35 | 32 | 27 | 24 |
| 6 | 11 | 37 | 34 | 28 | 25 |
| 6 | 12 | 38 | 35 | 30 | 25 |
| 6 | 13 | 40 | 37 | 31 | 26 |
| 6 | 14 | 42 | 38 | 32 | 27 |
| 6 | 15 | 44 | 40 | 33 | 28 |
| 6 | 16 | 46 | 42 | 34 | 29 |
| 6 | 17 | 47 | 43 | 36 | 30 |
| 6 | 18 | 49 | 45 | 37 | 31 |
| 6 | 19 | 31 | 46 | 38 | 32 |
| 6 | 20 | 33 | 48 | 39 | 33 |
| 7 | 7 | 39 | 36 | 32 | 29 |
| 7 | 8 | 41 | 58 | 34 | 30 |
| 7 | 9 | 43 | 40 | 35 | 31 |
| 7 | 10 | 45 | 42 | 37 | 33 |
| 7 | 11 | 47 | 44 | 38 | 34 |
| 7 | 12 | 49 | 46 | 40 | 35 |
| 7 | 13 | 52 | 48 | 41 | 36 |
| 7 | 14 | 54 | 30 | 43 | 37 |
| 7 | 13 | 36 | 32 | 44 | 38 |
| 7 | 16 | 58 | 54 | 46 | 39 |
| 7 | 17 | 61 | 56 | 47 | 41 |
| 7 | 18 | 63 | 58 | 49 | 42 |
| 7 | 19 | 65 | 60 | 50 | 43 |
| 7 | 20 | 67 | 62 | 32 | 44 |
| 8 | 8 | 51 | 49 | 43 | 40 |
| 8 | 9 | 54 | 51 | 45 | 41 |
| 8 | 10 | 56 | 53 | 47 | 42 |
| 8 | 11 | 59 | 53 | 49 | 44 |
| 8 | 12 | 62 | 38 | 31 | 45 |
| 8 | 13 | 64 | 60 | 53 | 47 |
| 8 | 14 | 67 | 62 | 54 | 48 |
| 8 | 15 | 69 | 65 | 56 | 50 |
| 8 | 16 | 72 | 67 | 38 | 51 |
| 8 | 17 | 75 | 70 | 60 | 33 |
| 8 | 18 | 77 | 72 | 62 | 54 |
| 8 | 19 | 80 | 74 | 64 | 56 |
| 8 | 20 | 83 | 77 | 66 | 57 |
| 9 | 9 | 66 | 62 | 56 | 52 |
| 9 | 10 | 69 | 63 | 38 | 53 |
| 9 | 11 | 72 | 63 | 61 | 55 |
| 9 | 12 | 75 | 71 | 63 | 57 |
| 9 | 13 | 78 | 73 | 63 | 39 |
| 9 | 14 | 81 | 76 | 67 | 60 |
| 9 | 15 | 84 | 79 | 69 | 62 |
| 9 | 16 | 87 | 82 | 72 | 64 |
| 9 | 17 | 90 | 84 | 74 | 66 |
| 9 | 18 | 93 | 87 | 76 | 68 |
| 9 | 19 | 96 | 90 | 78 | 70 |
| 9 | 20 | 99 | 93 | 81 | 71 |
| 10 | 10 | 82 | 78 | 71 | 65 |
| 10 | 11 | 86 | 81 | 73 | 67 |
| 10 | 12 | 89 | 84 | 76 | 69 |
| 10 | 13 | 92 | 88 | 79 | 72 |
| 10 | 14 | 96 | 91 | 81 | 74 |
| 10 | 13 | 99 | 94 | 84 | 76 |
| 10 | 16 | 103 | 97 | 86 | 78 |
| 10 | 17 | 106 | 100 | 89 | 80 |
| 10 | 18 | 110 | 103 | 92 | 82 |
| 10 | 19 | 113 | 107 | 94 | 84 |
| 10 | 20 | 117 | 110 | 97 | 87 |
| 11 | 11 | 100 | 96 | 87 | 81 |
| 11 | 12 | 104 | 99 | 90 | 83 |
| 11 | 13 | 108 | 103 | 93 | 86 |
| 11 | 14 | 112 | 106 | 96 | 88 |
| 11 | 15 | 116 | 110 | 99 | 90 |
| 11 | 16 | 120 | 113 | 102 | 93 |
| 11 | 17 | 123 | 117 | 103 | 95 |
| 11 | 18 | 127 | 121 | 108 | 98 |
| 11 | 19 | 131 | 124 | 111 | 100 |
| 11 | 20 | 133 | 128 | 114 | 103 |
| 12 | 12 | 120 | 113 | 103 | 98 |
| 12 | 13 | 123 | 119 | 109 | 101 |
| 12 | 14 | 129 | 123 | 112 | 103 |
| 12 | 15 | 133 | 127 | 115 | 106 |
| 12 | 16 | 138 | 131 | 119 | 109 |
| 12 | 17 | 142 | 135 | 122 | 112 |
| 12 | 18 | 146 | 159 | 125 | 115 |
| 12 | 19 | 150 | 143 | 129 | 118 |
| 12 | 20 | 155 | 147 | 132 | 120 |
| 13 | 15 | 142 | 136 | 125 | 117 |
| 15 | 14 | 147 | 141 | 129 | 120 |
| 13 | 15 | 152 | 145 | 153 | 123 |
| 13 | 16 | 156 | 150 | 156 | 126 |
| 13 | 17 | 161 | 154 | 140 | 129 |
| 13 | 18 | 166 | 158 | 144 | 135 |
| 13 | 19 | 171 | 163 | 148 | 136 |
| 13 | 20 | 175 | 167 | 151 | 139 |
| 14 | 14 | 166 | 160 | 147 | 137 |
| 14 | 13 | 171 | 164 | 151 | 141 |
| 14 | 16 | 176 | 169 | 153 | 144 |
| 14 | 17 | 182 | 174 | 159 | 148 |
| 14 | 18 | 187 | 179 | 163 | 151 |
| 14 | 19 | 192 | 183 | 168 | 153 |
| 14 | 20 | 197 | 168 | 172 | 159 |
| 15 | 15 | 192 | 184 | 171 | 160 |
| 15 | 16 | 197 | 190 | 175 | 163 |
| 15 | 17 | 203 | 195 | 180 | 167 |
| 13 | 18 | 208 | 200 | 184 | 171 |
| 13 | 19 | 214 | 205 | 189 | 173 |
| 15 | 20 | 220 | 210 | 193 | 179 |
| 16 | 16 | 219 | 211 | 196 | 184 |
| 16 | 17 | 225 | 217 | 201 | 188 |
| 16 | 18 | 251 | 222 | 206 | 192 |
| 16 | 19 | 237 | 228 | 210 | 196 |
| 16 | 20 | 243 | 234 | 215 | 201 |
| 17 | 17 | 249 | 240 | 225 | 210 |
| 17 | 18 | 255 | 246 | 228 | 214 |
| 17 | 19 | 262 | 252 | 234 | 219 |
| 17 | 20 | 268 | 258 | 239 | 223 |
| 18 | 18 | 280 | 270 | 252 | 237 |
| 18 | 19 | 287 | 277 | 258 | 242 |
| 18 | 20 | 294 | 283 | 263 | 247 |
| 19 | 19 | 313 | 303 | 283 | 267 |
| 19 | 20 | 320 | 309 | 289 | 272 |
| 20 | 20 | 348 | 337 | 313 | 298 |

Table 5. Breaking loads for the system glass-reinforced plastic bonded with EC-2214

| Hand sanding 7 days at 73°F + 50% RH | | Machine sanding 7 days at 73°F + 50% RH | | Hand sanding 30 days at 120°F + 95% RH | | Machine sanding 30 days at 120°F + 95% RH | |
|---|---|---|---|---|---|---|---|
| N | LBS | N | LBS | N | LBS | N | LBS |
| | 417 (VI) | 2910 | 655 (V) | | 610 (IV) | | 680 (VI) |
| | 507 (VI) | 2940 | 660 (VI) | 2830 | 635 (VI) | 3470 | 780 (VI) |
| | 540 (IV) | 3230 | 725 (V) | 2870 | 645 (VI) | 3560 | 800 (I) |
| | 610 (IV) | 3380 | 760 (V) | 2890 | 650 (VI) | 3600 | 810 (VI) |
| 3070 | 690 (VI) | 3390 | 761 (VI) | 2910 | 655 (VI) | 3600 | 810 (VI) |
| 3160 | 710 (IV) | 3400 | 765 (VI) | 2960 | 665 (V) | 3670 | 825 (VI) |
| | 721 (VI) | 3400 | 765 (II) | 2980 | 670 (V) | 3780 | 850 (V) |
| 3230 | 725 (V) | 3460 | 778 (VI) | 3160 | 710 (VI) | 3890 | 875 (III) |
| 3250 | 730 (III) | 3540 | 795 (VI) | 3180 | 715 (III) | 3920 | 880 (III) |
| | 731 (VI) | 3650 | 820 (III) | 3200 | 720 (V) | 3920 | 880 (V) |
| 3380 | 760 (III) | 3760 | 845 (III) | 3290 | 740 (III) | 3940 | 885 (III) |
| 3520 | 790 (III) | 3830 | 860 (IV) | 3320 | 745 (III) | 4010 | 900 (IV) |
| 3560 | 800 (II) | 3890 | 875 (II) | 3320 | 745 (IV) | 4050 | 910 (II) |
| 3600 | 810 (IV) | 3980 | 895 (III) | 3470 | 780 (V) | 4050 | 910 (II) |
| 3650 | 820 (V) | 4050 | 910 (V) | 3540 | 795 (II) | 4070 | 915 (IV) |
| 3670 | 825 (III) | 4140 | 930 (III) | 3560 | 800 (III) | 4090 | 920 (III) |
| 3780 | 850 (I) | 4210 | 945 (I) | 3600 | 810 (II) | 4090 | 920 (IV) |
| 3780 | 850 (II) | 4210 | 945 (IV) | 3690 | 830 (III) | 4270 | 960 (II) |
| 3830 | 860 (I) | 4290 | 965 (III) | 3690 | 830 (IV) | 4325 | 970 (IV) |
| 3870 | 870 (I) | 4340 | 975 (IV) | 3740 | 840 (IV) | 4340 | 975 (I) |
| 3890 | 875 (V) | 4380 | 985 (IV) | 3760 | 845 (V) | 4410 | 990 (II) |
| 3890 | 875 (V) | 4520 | 1015 (IV) | 3850 | 865 (I) | 4440 | 998 (V) |
| 3940 | 885 (III) | 4560 | 1025 (I) | 3850 | 865 (IV) | 4500 | 1012 (V) |
| 4050 | 910 (V) | 4560 | 1025 (V) | 3890 | 875 (I) | 4520 | 1015 (I) |
| 4120 | 925 (IV) | 4650 | 1045 (I) | 3920 | 880 (I) | 4520 | 1015 (III) |
| 4230 | 950 (II) | 4720 | 1060 (II) | 4010 | 900 (I) | 4560 | 1025 (I) |
| 4290 | 965 (II) | 4720 | 1060 (II) | 4120 | 925 (II) | 4650 | 1045 (IV) |
| 4430 | 995 (II) | 4810 | 1080 (I) | 4320 | 970 (II) | 4900 | 1100 (V) |
| 4580 | 1030 (I) | 4940 | 1110 (II) | 4340 | 975 (I) | 5070 | 1140 (I) |
| 4610 | 1035 (I) | 5300 | 1190 (I) | 4340 | 975 (II) | 5670 | 1275 (II) |

I = 1-4 hrs SET; II = 1 day SET; III = 2 days SET;

IV = 7 days SET; V = 14 days SET; VI = 30 days SET

Table 6. Breaking loads for the system glass-reinforced plastic bonded with AF-126

| Hand sanding 7 days at 73°F + 50% RH | | Machine sanding 7 days at 73°F + 50% RH | | Hand sanding 30 days at 120°F + 95% RH | | Machine sanding 30 days at 120°F + 95% RH | |
|---|---|---|---|---|---|---|---|
| N | LBS | N | PSI | N | PSI | N | PSI |
| 3800 | 853 (VI) | | 917 (VI) | 3430 | 770 (IV) | 4010 | 900 (II) |
| 4010 | 900 (II) | 4320 | 970 (II) | 3450 | 775 (II) | 4120 | 925 (VI) |
| 4110 | 924 (VI) | 4340 | 975 (IV) | 3450 | 775 (II) | 4160 | 935 (I) |
| 4120 | 925 (IV) | | 1027 (VI) | 3580 | 805 (IV) | 4230 | 950 (IV) |
| 4290 | 963 (VI) | 4650 | 1045 (IV) | 3630 | 815 (III) | 4270 | 960 (III) |
| 4290 | 965 (III) | 4670 | 1050 (III) | 3690 | 830 (III) | 4270 | 960 (V) |
| 4340 | 975 (II) | 4570 | 1065 (II) | 3850 | 865 (IV) | 4430 | 995 (II) |
| 4380 | 985 (I) | 4780 | 1075 (II) | 3870 | 870 (II) | 4450 | 1000 (I) |
| 4410 | 990 (I) | 4900 | 1100 (I) | 3940 | 885 (I) | 4450 | 1000 (II) |
| 4520 | 1015 (I) | 4900 | 1100 (II) | 4030 | 905 (III) | 4470 | 1005 (III) |
| 4550 | 1023 (VI) | 4940 | 1110 (III) | 4070 | 915 (II) | 4580 | 1030 (III) |
| 4560 | 1025 (IV) | 4980 | 1119 (VI) | 4090 | 920 (IV) | 4630 | 1040 (V) |
| 4630 | 1040 (V) | 4980 | 1120 (III) | 4230 | 950 (VI) | 4650 | 1045 (III) |
| 4670 | 1050 (II) | 5010 | 1125 (I) | 4320 | 970 (I) | 4720 | 1060 (IV) |
| 4720 | 1060 (II) | 5010 | 1125 (III) | 4450 | 1000 (V) | 4740 | 1065 (II) |
| 4780 | 1075 (IV) | 5090 | 1144 (VI) | 4470 | 1005 (V) | 4760 | 1070 (I) |
| 4850 | 1090 (IV) | 5230 | 1175 (III) | 4470 | 1005 (V) | 4810 | 1080 (VI) |
| 4870 | 1094 (VI) | 5250 | 1180 (I) | 4490 | 1010 (V) | 4830 | 1085 (VI) |
| 4960 | 1115 (III) | 5250 | 1180 (IV) | 4490 | 1010 (VI) | 4830 | 1085 (VI) |
| 4980 | 1120 (III) | 5250 | 1180 (IV) | 4520 | 1015 (III) | 4960 | 1115 (IV) |
| 5010 | 1125 (V) | 5410 | 1215 (IV) | 4540 | 1020 (III) | 5010 | 1125 (IV) |
| 5070 | 1140 (I) | 5450 | 1225 (V) | 4540 | 1020 (VI) | 5070 | 1140 (III) |
| 5100 | 1145 (IV) | 5470 | 1230 (VI) | 4580 | 1030 (IV) | 5100 | 1145 (VI) |
| 5380 | 1210 (II) | 5540 | 1245 (V) | 4610 | 1035 (VI) | 5120 | 1150 (V) |
| 5430 | 1220 (V) | 5540 | 1245 (V) | 4670 | 1050 (VI) | 5150 | 1158 (V) |
| 5500 | 1235 (III) | 5220 | 1285 (II) | 4690 | 1055 (II) | 5160 | 1160 (I) |
| 5500 | 1235 (III) | 5760 | 1295 (I) | 5030 | 1130 (V) | 5300 | 1190 (I) |
| 5630 | 1265 (I) | 5850 | 1315 (V) | 5070 | 1140 (I) | 5340 | 1200 (II) |
| 5240 | 1290 (V) | 6050 | 1360 (I) | 5180 | 1165 (I) | 5450 | 1225 (IV) |
| 6070 | 1365 (V) | 6140 | 1380 (V) | 5230 | 1175 (I) | 5460 | 1227 (V) |

I = 1-4 hrs SET; II = 1 day SET; III = 2 days SET;

IV = 7 days SET; V = 14 days SET; VI = 30 days SET

Table 7. t test summary table

| Conditions | $n$ | DF | Mean | Sum of squares $(Y_1 - \bar{Y})^2$ |
|---|---|---|---|---|
| Hand - 7 days | 30 | 29 | 1080 | 457,400 |
| Hand - 30 days | 30 | 29 | 960 | 393,800 |
| Machine - 7 days | 30 | 29 | 1150 | 375,800 |
| Machine - 30 days | 30 | 29 | 1070 | 247,600 |

$n$ = Number of samples tested
DF = Degrees of freedom = $n - 1$
$\bar{Y}$ = Mean
$Y_1$ = Value for individual data joint

Table 8. t test table

| Degrees Of Freedom n | Probability of no significant difference between M and m P = 10% | P = 5% | P = 1% | P = 0.2% |
|---|---|---|---|---|
| 3 | t = 2.92 | 4.30 | 9.92 | 22.33 |
| 4 | 2.35 | 3.18 | 5.84 | 10.21 |
| 5 | 2.13 | 2.78 | 4.60 | 7.17 |
| 6 | 2.02 | 2.57 | 4.03 | 5.89 |
| 7 | 1.94 | 2.45 | 3.71 | 5.21 |
| 8 | 1.89 | 2.36 | 3.50 | 4.79 |
| 9 | 1.86 | 2.31 | 3.36 | 4.50 |
| 10 | 1.83 | 2.26 | 3.25 | 4.30 |
| 11 | 1.81 | 2.23 | 3.17 | 4.14 |
| 12 | 1.80 | 2.20 | 3.11 | 4.02 |
| 13 | 1.78 | 2.18 | 3.05 | 3.93 |
| 14 | 1.77 | 2.16 | 3.01 | 3.85 |
| 15 | 1.76 | 2.14 | 2.98 | 3.79 |
| 16 | 1.75 | 2.13 | 2.95 | 3.73 |
| 17 | 1.75 | 2.12 | 2.92 | 3.69 |
| 18 | 1.74 | 2.11 | 2.90 | 3.65 |
| 19 | 1.73 | 2.10 | 2.88 | 3.61 |
| 20 | 1.73 | 2.09 | 2.86 | 3.58 |
| 21 | 1.72 | 2.09 | 2.85 | 3.55 |
| 22 | 1.72 | 2.08 | 2.83 | 3.53 |
| 23 | 1.72 | 2.07 | 2.82 | 3.50 |
| 24 | 1.71 | 2.07 | 2.81 | 3.48 |
| 25 | 1.71 | 2.06 | 2.80 | 3.47 |
| 26 | 1.71 | 2.06 | 2.79 | 3.45 |
| 27 | 1.71 | 2.06 | 2.78 | 3.44 |
| 28 | 1.70 | 2.05 | 2.77 | 3.42 |
| 29 | 1.70 | 2.05 | 2.76 | 3.41 |
| 30 | 1.70 | 2.05 | 2.76 | 3.40 |
| 40 | 1.68 | 2.02 | 2.70 | 3.31 |
| 60 | 1.67 | 2.00 | 2.66 | 3.23 |
| 120 | 1.66 | 1.98 | 2.62 | 3.16 |
| 00 | 1.64 | 1.96 | 2.58 | 3.09 |

From ref. 2.

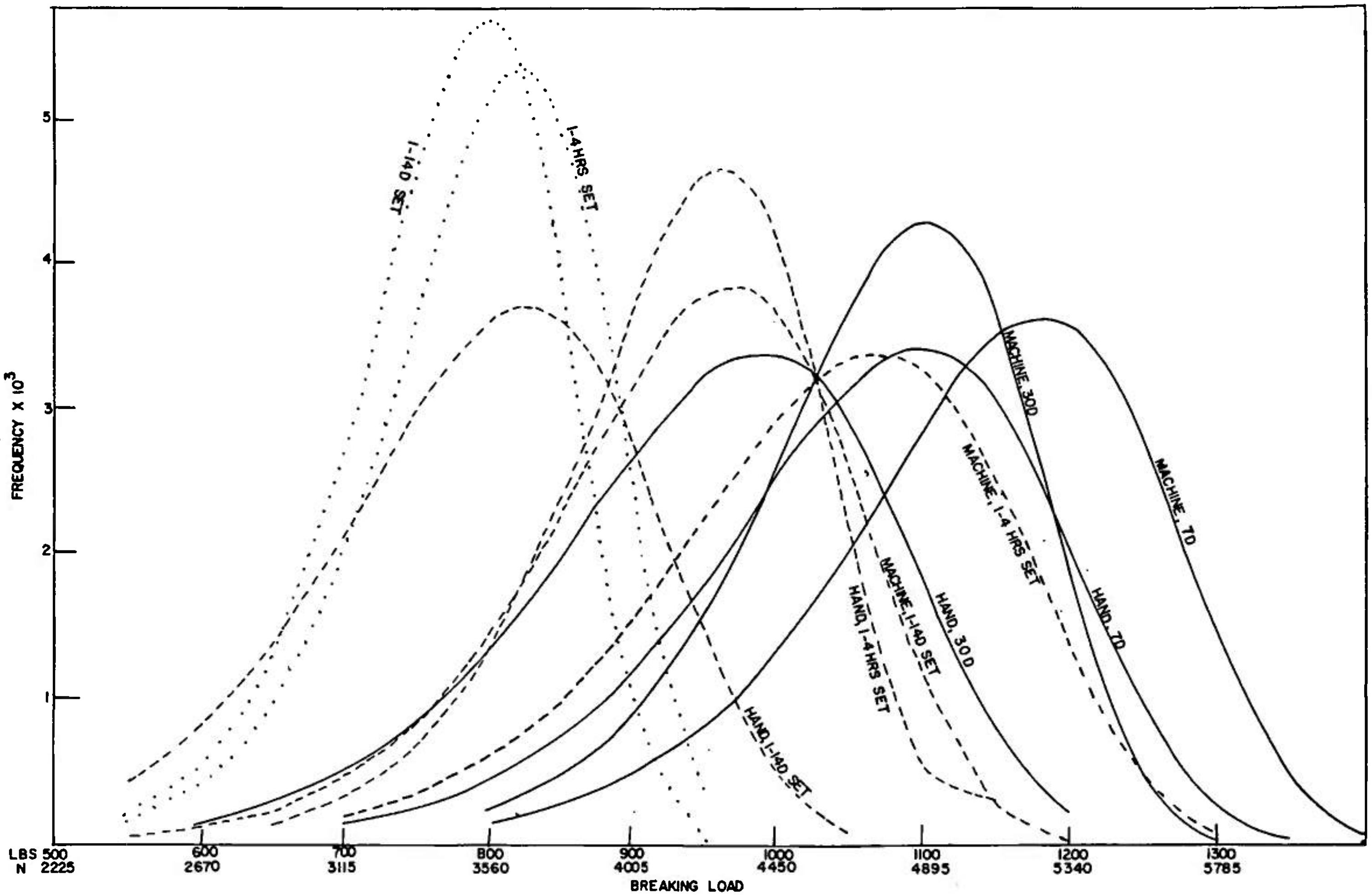


Figure 1. Differential Weibull distribution curves for lap shear data after various treatments. AF-126——; EC-2214----; Epon 828/V-140....

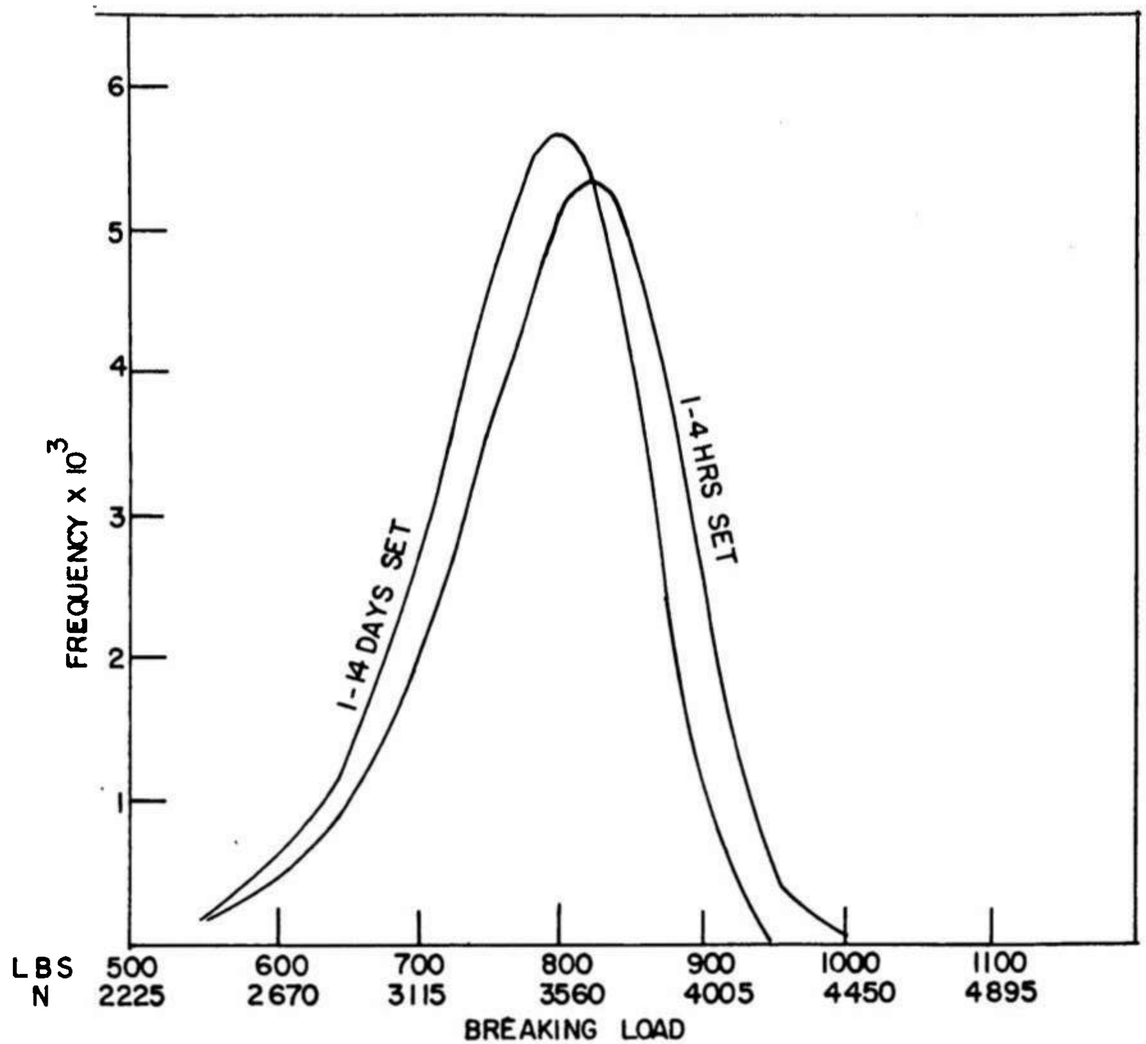


Figure 2. Differential Weibull distribution curves for Epon 828/V-140.

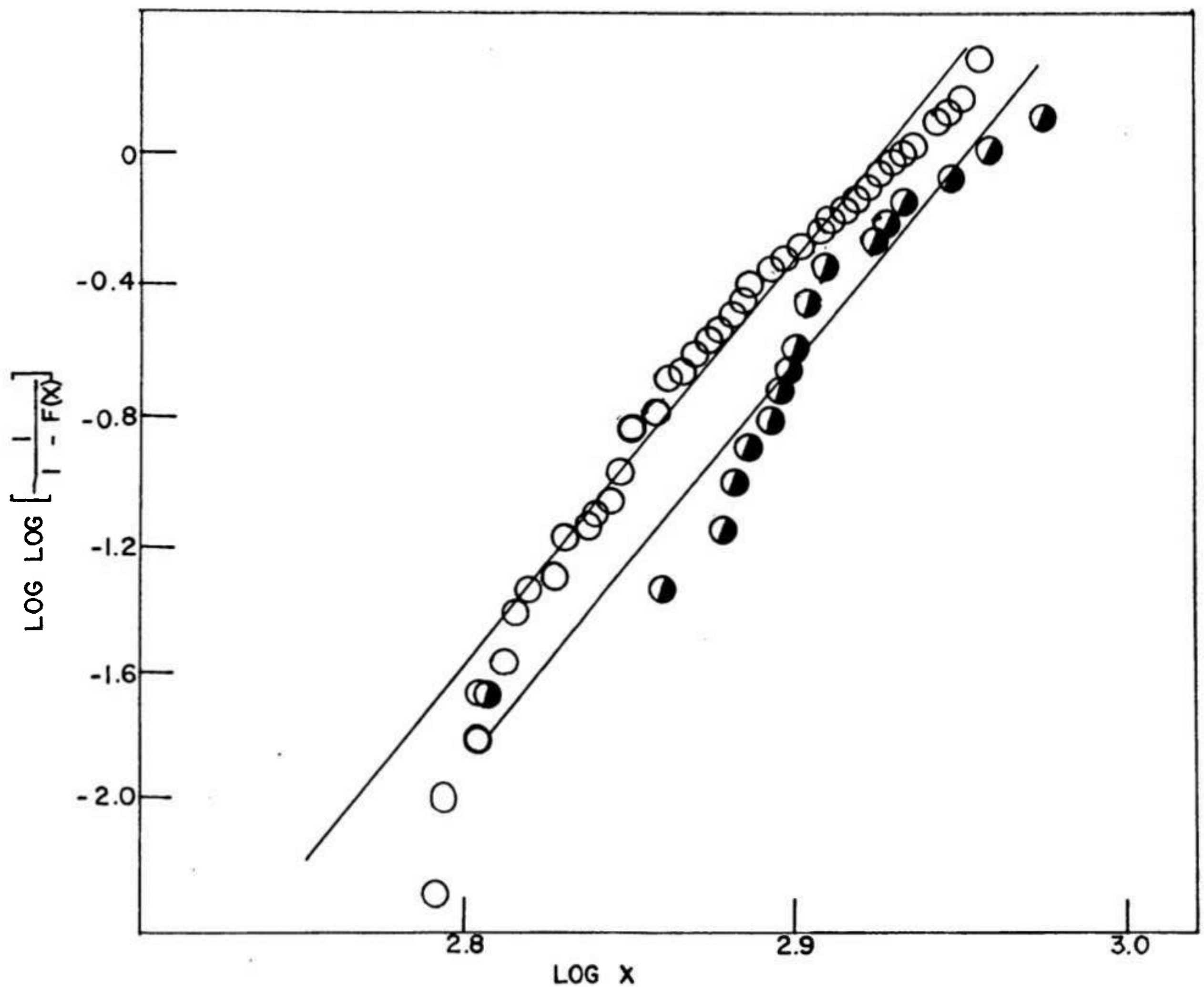


Figure 3. Linear Weibull distribution for Epon 828/V-140.
O = 1-14 days SET; ◐ = 1-4 hrs SET.

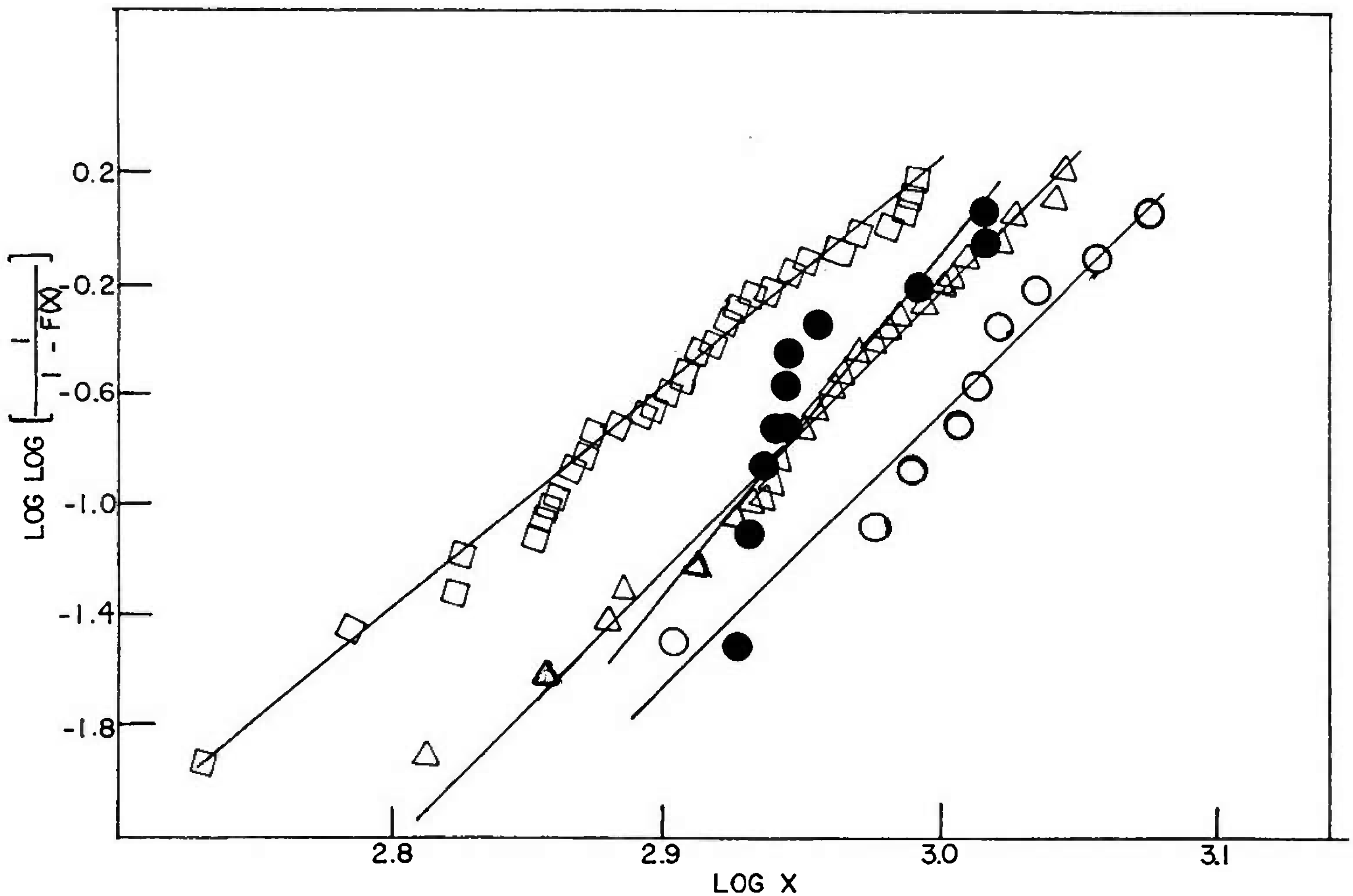


Figure 4. Linear Weibull distribution for EC-2214, O = Machine sanding, 1-4 hrs SET; Δ = machine sanding, 1-14 days SET; ● = hand sanding, 1-4 hrs SET; □ = hand sanding, 1-14 days SET.

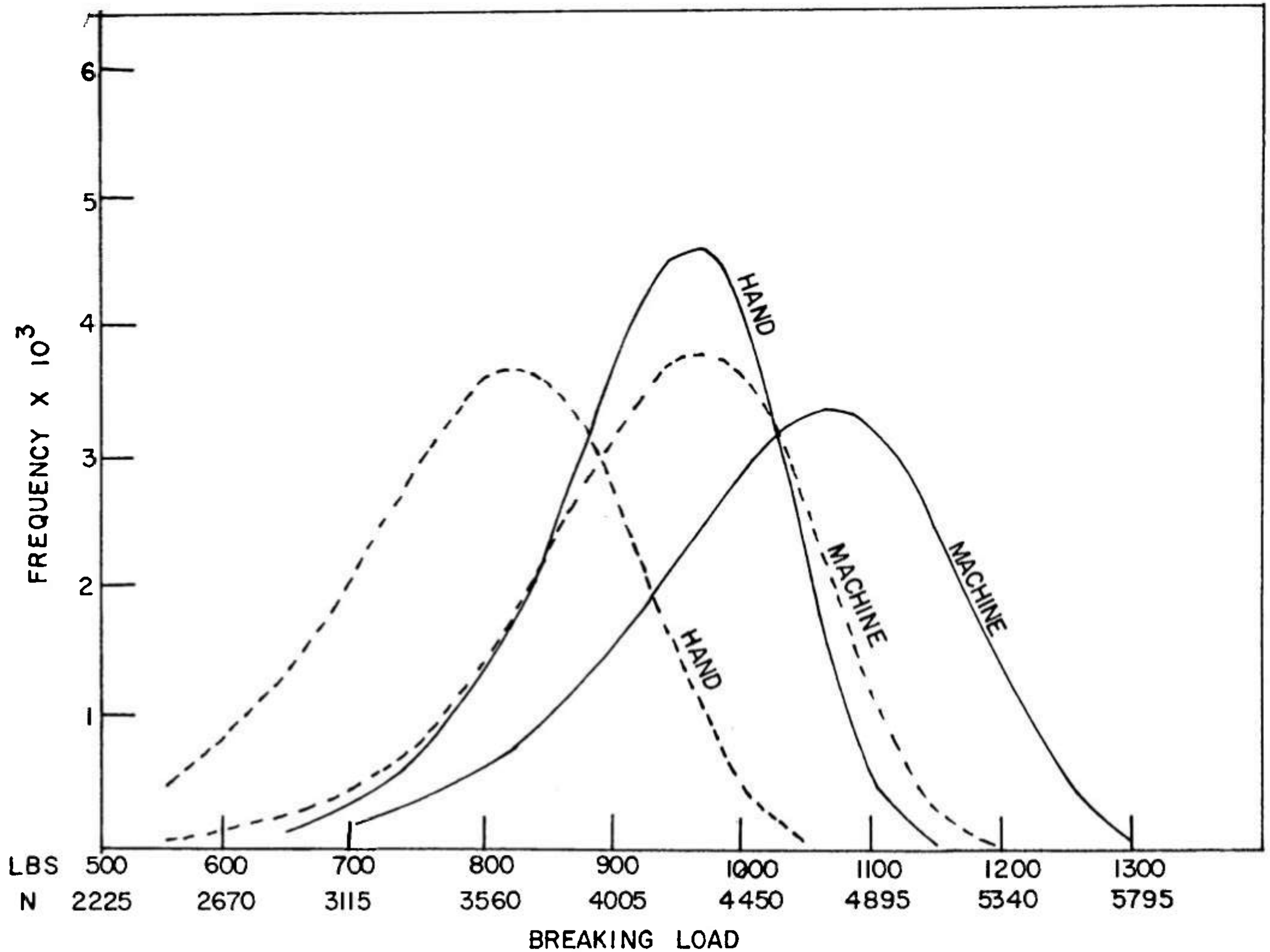


Figure 5. Differential Weibull distribution curves for EC-2214,
—— = 1-4 hrs SET; ---- = 1-14 days SET.

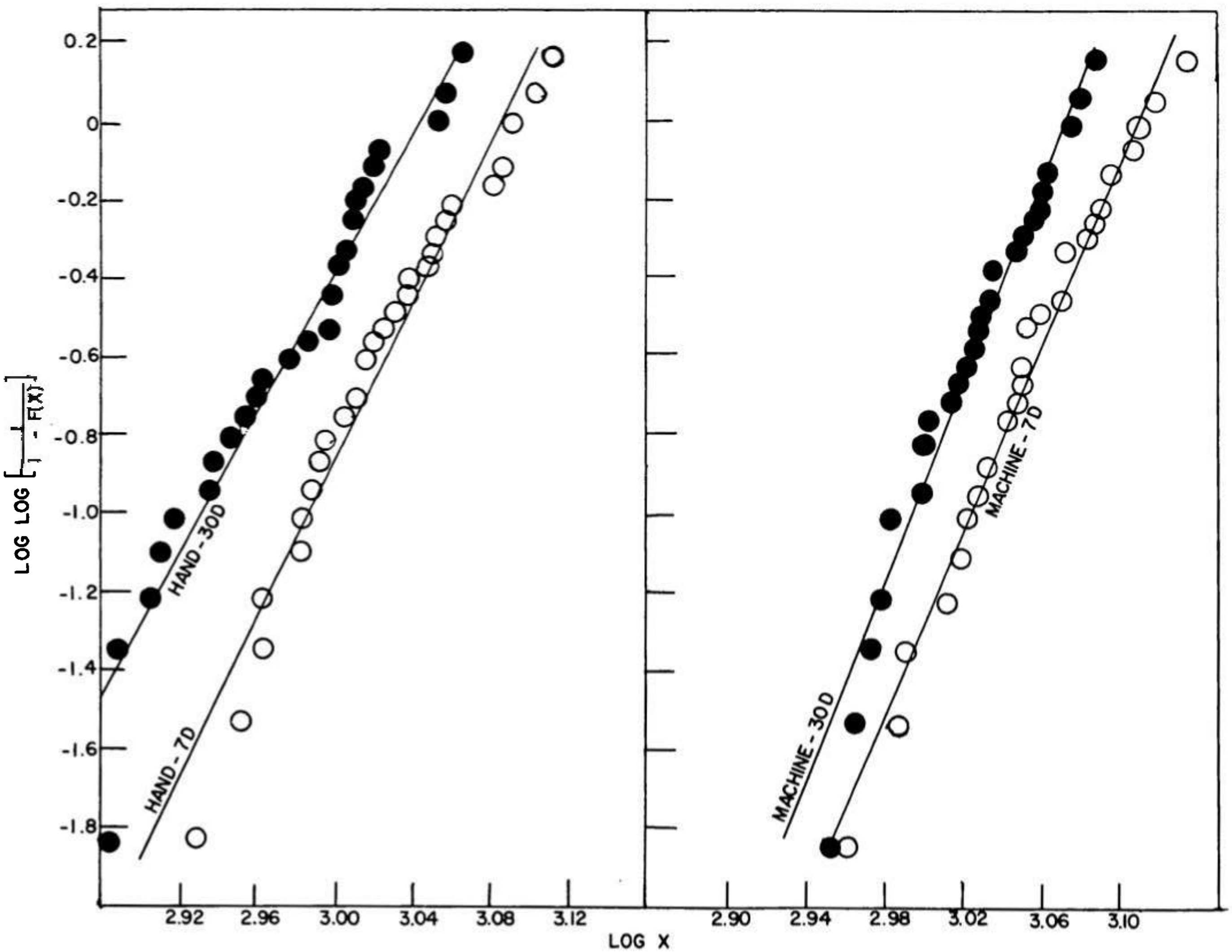


Figure 6. Linear Weibull distribution for AF-126.

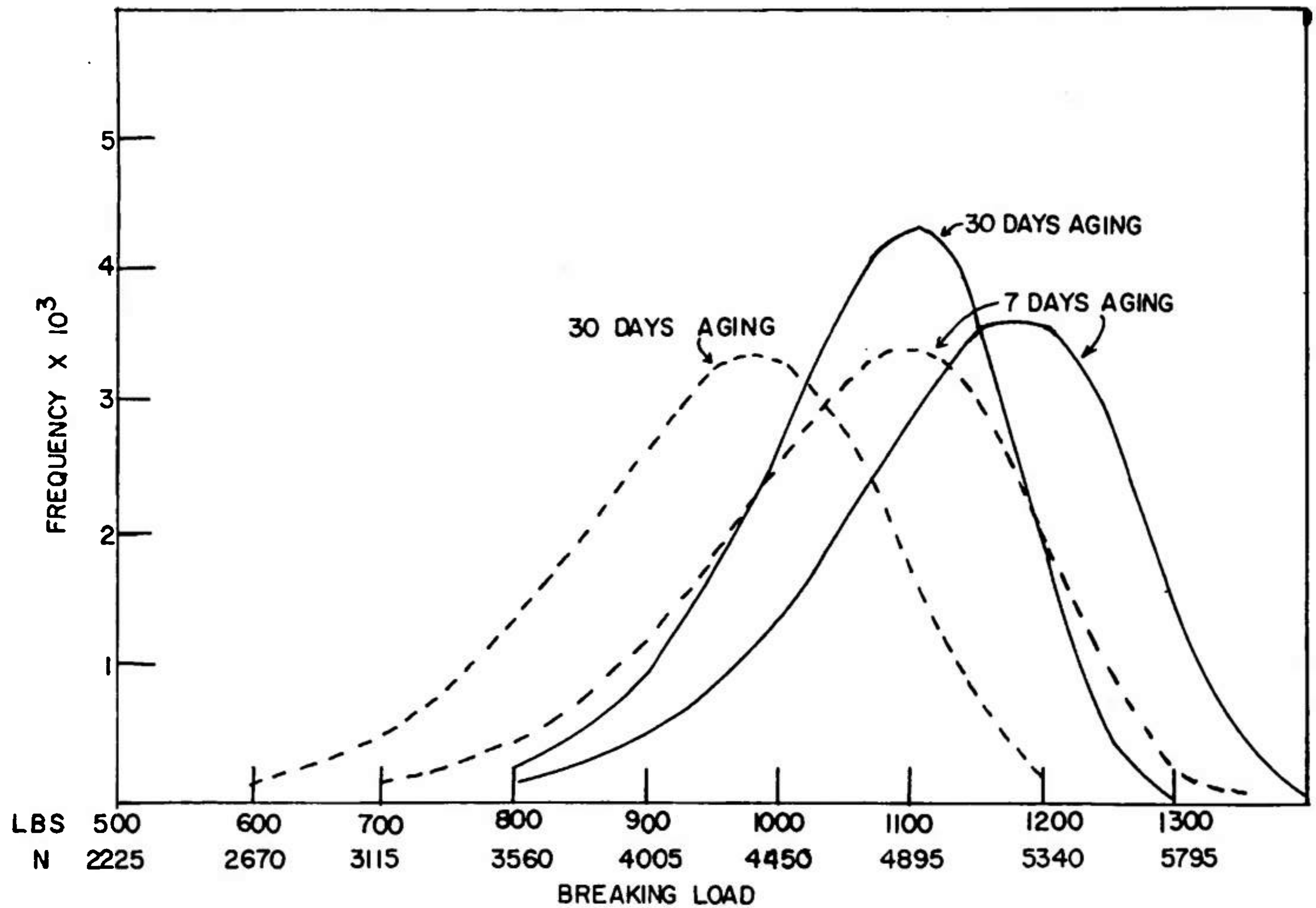


Figure 7. Differential Weibull distribution curves for AF-126.
—— = machine sanding; ---- = hand sanding.

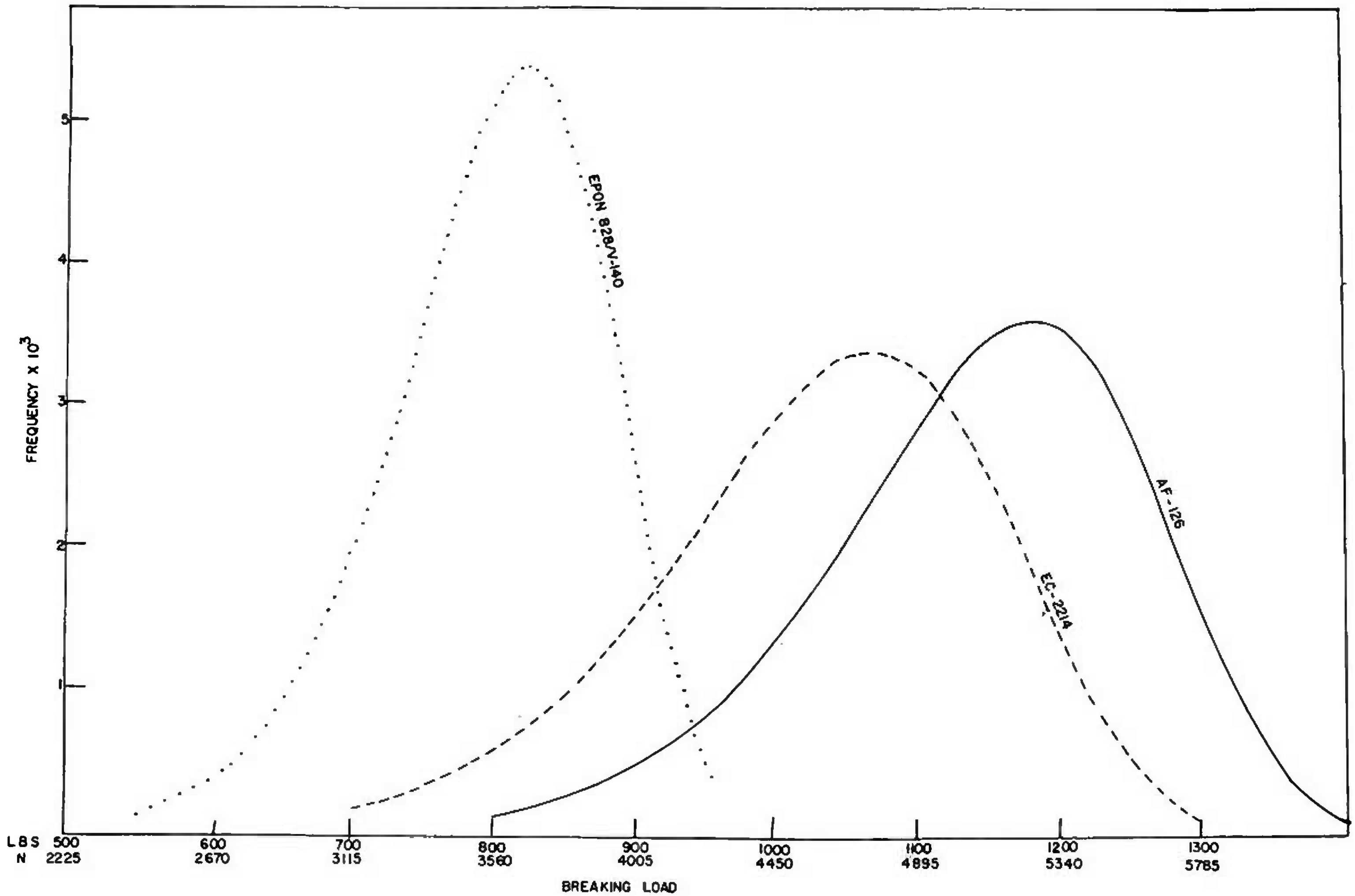


Figure 8. Comparison of adhesives under optimum conditions.

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